



# Projections for temperature-related years of life lost from cardiovascular diseases in the elderly in a Chinese city with typical subtropical climate

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## ABSTRACT

**Objective:** Extreme temperature is an important risk factor for cardiovascular diseases, and the elderly are particularly vulnerable to temperature variation. Global warming and the increasingly aging population are two major global challenges for human health; thus, an urgent need exists to project the temperature-related cardiovascular disease burden regarding both of the aforementioned factors. We aimed to the project temperature-related burden of cardiovascular diseases using years of life lost (YLL) in the elderly in a Chinese city with typical subtropical climate.

**Methods:** A retrospective time-series study was first conducted to estimate cardiovascular disease burden associated with temperature in the elderly from 2008 to 2015 in Ningbo, China. Then, future projections considering demographic change and adaptation under 19 global-scale climate models (GCMs) and 3 different Representative Concentration Pathways (RCPs) scenarios for the 2050s and 2070s were estimated.

**Results:** The exposure-response curve for temperature on YLL from cardiovascular diseases was U-shaped, with increased YLL for both higher- and lower- than optimal temperature. The projected annual increase in heat-related YLL was outweighed by the decrease in cold-related YLL. However, monthly analysis demonstrated that temperature-related YLL will increase significantly in August. Additionally, heat-related YLL is projected to increase 3.1–11.5 times for the 2050s and 2070s relative to baseline, when considering demographic changes, even with 30% adaptation taken into consideration.

**Conclusions:** Although annual YLL from cardiovascular diseases in the elderly associated with temperature will decrease in the future, heat-related YLL will increase tremendously, which indicates that more adaptation strategies and greenhouse emission control measures should be undertaken to reduce the future heat-related burden of cardiovascular diseases in the elderly.

## 1. Introduction

Cardiovascular diseases are the leading cause of death and

disability-adjusted years of life lost worldwide, placing a great social and economic burden on public health systems (Lozano et al., 2012). Epidemiological studies have demonstrated that extreme temperature is

**Abbreviations:** CMIP5, Coupled Model Intercomparison Project Phase 5; DLNM, distributed lag nonlinear model; GCMs, global-scale climate models; GLM, generalized linear model; ICD-10, International Classification of Disease, 10th version; IPCC AR5, Intergovernmental Panel on Climate Change Fifth Assessment Report; OT, optimal temperature; RCPs, Representative Concentration Pathways; UN, United Nations; WCRP, World Climate Research Programme; YLL, years of life lost

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an important risk factor for cardiovascular diseases (Yang et al., 2017; Song et al., 2017). Both high and low temperatures were related to the increased mortality from cardiovascular diseases. The potential mechanisms underlying the association between temperature and cardiovascular diseases involve multiple physiopathology regulations, which include cold-enhanced sympathetic reactivity, cold-activated renin-angiotensin system, both cold- and heat-mediated dehydration, and heat stroke-induced systemic inflammatory response (Liu et al., 2015). In addition, the elderly, who are more sensitive to temperature variations, constitute the largest proportion of cardiovascular deaths (Zheng et al., 2016).

Global warming and the increasingly aging population are two major global challenges for human health in the 21st century (Costello et al., 2009; Li et al., 2016). According to the Intergovernmental Panel on Climate Change Fifth Assessment Report (IPCC AR5), the global mean surface temperature has been projected to rise in the future, although the magnitude of this temperature increase varies under different Representative Concentration Pathways (RCPs) (IPCC, 2013). Global warming may lead to increased heat-related deaths (Chen et al., 2017; Huang et al., 2011; Knowlton et al., 2007; Peng et al., 2011; Sheridan et al., 2012), but also may result in reduced cold-related deaths (Langford and Bentham, 1995). However, limited studies have considered both heat- and cold- related health effects (Ballester et al., 2011; Guo et al., 2016; Huang et al., 2012; Li et al., 2013), and the net effect of global warming on annual temperature-related deaths remains uncertain under current and projected future climates.

China is now confronted with both of abovementioned challenges. The annual average temperature in the mainland area of China has increased by 0.21–0.25 °C in the past 50–60 years, and the trend has projected it to accelerate in the 21st century (IPCC, 2013). Furthermore, the number of the elderly in China will rapidly increase in the mid- and late- 21st century compared with the beginning of the century (United Nations, 2015). There is an urgent need to project temperature-related cardiovascular diseases burden considering both challenges, and it has significant meaning for public health intervention and policy making.

Furthermore, most of the studies that have explored the effects of temperature used mortality as the health indicator, which only consider the number of deaths (Li et al., 2016; Lee and Kim, 2016). Giving the same weight to deaths occurring at different ages may distort resource allocation and policy priorities (Lopez et al., 2006). Compared with mortality, years of life lost (YLL) takes both the number of deaths and the life expectancy at death into consideration and gives higher weights to those that occur at younger ages (Guo et al., 2013). It can provide more informative measurement for quantifying temperature-related premature deaths.

In this research, we made future projections for temperature-related YLL from cardiovascular diseases in the elderly population of Ningbo, China. Ningbo is located in the Yangtze River Delta in South China, and it is the world's fourth largest port city with a population of 7.83 million in 2015. It is a coastal city with a typical subtropical climate, with hot, wet summers and mild, dry winters. Exploring the temperature effect in this city can provide indications for other cities with subtropical climate. Different climate change scenarios and the aging population were both considered. In addition, considering human might adapt to a diverse range of climate (Gasparrini et al., 2015a; Huang et al., 2015), future adaptation of the population was also accounted for in this study.

## 2. Data and methods

### 2.1. Data collection

We collected historical data on the daily number of deaths due to cardiovascular diseases in the population age  $\geq 75$  years from Jan 1st, 2008 to Dec 31st, 2015 in Ningbo from Ningbo Municipal Center for Disease Control and Prevention. The same age cut-off value has been

used in previous studies to define the elderly (Lu et al., 2015; Yang et al., 2016). All deaths from cardiovascular diseases (I00–I99) were restricted to the residents of Ningbo and coded by International Classification of Disease, 10th version (ICD-10). Daily death counts were defined as the number of deaths occurring on a single day. YLL was calculated by matching the patient's age to the World Health Organization standard life table for each death, and daily YLL was the sum of all cardiovascular deaths in the elderly occurring on the same day.

Daily meteorological data including temperature and relative humidity were obtained for the same period from the Ningbo Meteorological Bureau. The Meteorological Bureau collected the meteorological data from 169 monitoring stations which cover the all 11 urban and rural areas of Ningbo. The monitoring stations are local city-level stations called synoptic eye automatic weather stations, which all use the same instruments. The daily averages for the whole city were derived from all these sites. A map of all the automatic meteorological stations were provided (Supplemental material, Fig. S1).

### 2.2. Statistical analysis

#### 2.2.1. Baseline temperature-YLL relationships

Distributed lag nonlinear model (DLNM) was used to measure the nonlinear and delayed effects of temperature on YLL from cardiovascular deaths between 2008 and 2015 (Gasparrini et al., 2010). Because daily YLL from cardiovascular deaths in the elderly followed a normal distribution, generalized linear model (GLM) with the Gaussian family was used. Seasonal, long-term trend, day of the week and relative humidity were adjusted. Seasonal and long-term trend was controlled using a natural cubic spline function with 7 degrees per year. Day of the week was controlled as a categorical variable. The daily relative humidity was controlled using a natural cubic spline with 3 degrees of freedom.

The exposure-response curve was modeled with a natural cubic spline with 3 internal knots placed at equally spaced temperature percentiles (25th, 50th and 75th), and the lag-response function with 3 internal knots was placed at equally spaced values on the log scale. The models were tested by checking the residuals to ensure that the autocorrelation had been removed. There are convincing evidence that current factors controlling are able to explore the health effects of temperature (Guo et al., 2016; Gasparrini et al., 2015b).

Optimal temperature (OT) was determined based on the exposure-response curve for the daily maximum temperature on YLL from cardiovascular deaths. OT is the value corresponding to the minimum YLL value, and it was used as a reference temperature to calculate the increased YLL associated with higher or lower temperature than the OT.

To make a comparison, mortality risk from cardiovascular diseases in the elderly related to temperature was also estimated in the study. The same independent variables were used as in the models of YLL, except a quasi-Poisson family was used considering the distribution of the number of deaths.

#### 2.2.2. Future projections

Future temperature-related YLL from cardiovascular deaths in the elderly were projected by integrating the temperature projections for 19 global-scale climate models (GCMs) under 3 RCPs with baseline exposure-response relationships estimated from 2008 to 2015 in Ningbo. These 8 years were used as the baseline to avoid influences of any unusual temperature variance from a single year, and the data were centered on the year 2011.

Three RCPs used in this analysis were 3 greenhouse gas concentration trajectories adopted by the IPCC AR5, including RCP2.6, the mild emission scenario; RCP4.5, the medium emission scenario; and RCP8.5, the high emission scenario.

The projected daily temperatures for periods of 2046–2065 centered on the 2050s, and 2061–2080 were centered on the 2070s and were developed from 19 GCMs from the World Climate Research Programme

(WCRP) Coupled Model Intercomparison Project Phase 5 (CMIP5) multimodel dataset (Supplemental material, Table S1). Projections and changes of heat-related YLL and cold-related YLL, as well as whole year YLL were calculated. Furthermore, monthly changes in the future temperature-related YLL were also computed and compared with the baseline.

### 2.2.3. Adaptation and demographic change

People will adapt to the warming climate through a number of measures, thus adaptation to heat was taken into consideration. A recent study demonstrated the heat effect on persons 65 years and older decreased by approximately 30% in the 20th century (Petkova et al., 2014). Considering that ownership of air conditioning has increased dramatically over this period, we set 30% as the reference adaptation rate. Since the temperature-YLL relationship may not remain stable over time, due to population adaptation, we modeled the adaptation by shifting the OT and shape of temperature-YLL curves, as used in a previous study (Ballester et al., 2011), and the percent adaptation needed to offset the projected YLL was defined where the slopes cross the horizontal line at zero.

In addition to adaptation, demographic changes in the elderly were also considered. According to the low-, medium- and high-variant scenarios of population growth among the elderly aged 75 and above in China developed by the United Nations (UN) (United Nations, 2015), the number of individuals in this population will rapidly increase by 4.64 and 5.46 times in the 2050s and 2070s, respectively, when compared with the baseline population in 2011. Thus, the estimation of temperature-related YLL from cardiovascular death was also made accounting for demographic changes in the elderly population.

### 2.2.4. Sensitivity analysis

Sensitivity analysis were performed to check whether the results were robust to parameters changes within the models, including using the Chinese standard life table to calculate YLL, and estimating YLL from temperatures that have significant effects.

All analysis was performed with R software (version 3.1.2). The study was approved by the Institutional Review Board of Ningbo Municipal Center for Disease Control and Prevention (No. IRB 201603).

## 3. Results

### 3.1. Baseline associations between temperature and YLL

The mean daily maximum temperature in Ningbo, China from 2008 to 2015 was 22.2 °C, with a range from 7.2 °C to 35.9 °C. The average daily maximum temperatures under 19 global-scale climate models and 3 different future climate scenarios were presented in Table 1. A total of 60,118 cardiovascular deaths in the elderly were identified during the study period, and the corresponding YLL were 723,967.0 years. The mean daily number of deaths due to cardiovascular diseases was 21, and the corresponding mean daily YLL was 248.0 years.

The exposure-response curves for temperature on YLL due to cardiovascular diseases in the elderly during the period from 2008 to 2015 displayed a U-shape, with OT of 32.3 °C. Higher or lower temperature than this will cause increased YLL from cardiovascular deaths (Fig. 1).

The lag effects of temperature on YLL from cardiovascular deaths were different for cold and hot effects. The effect of cold temperatures showed a peak 2–3 days after exposure and declined gradually over the following 20 days, while the effect of hot temperatures appeared acutely on the day of exposure and decreased rapidly over the following 2 days (Fig. 2). Therefore, in our main analysis, considering characteristics of the exposure-response curve of both hot and cold temperature, we adopted the cumulative effects of three days (lag0–2) and twenty-one days (lag0–20) for high and low temperature, respectively. We defined high temperature as a temperature that was higher than the

**Table 1**

Baseline meteorological conditions from 2008 to 2015 in Ningbo, China, and projected temperatures under 19 global-scale climate models and 3 different future climate scenarios in the 2050s and 2070s.

Variables	Mean ± SD	Min	25th	50th	75th	Max
<b>Meteorological conditions</b>						
Daily maximum temperature (°C)	22.2 ± 8.4	7.2	14.8	23.6	29.1	35.9
Daily Relative humidity (%)	73.2 ± 12.0	19.0	66.0	74.0	82.0	97.0
<b>Projections of Tmax (°C)</b>						
2050s	RCP2.6	22.3 ± 8.1	8.7	14.8	23.4	29.5
	RCP4.5	22.6 ± 8.2	9.0	15.0	23.7	29.9
	RCP8.5	23.2 ± 8.1	9.6	15.7	24.2	30.2
2070s	RCP2.6	22.4 ± 8.1	8.7	14.8	23.4	29.5
	RCP4.5	23.1 ± 8.1	9.4	15.5	24.1	30.3
	RCP8.5	24.3 ± 8.2	10.7	16.7	25.3	31.5

Tmax: daily maximum temperature. RCP2.6, the mild emission scenario; RCP4.5, the medium emission scenario; and RCP8.5, the high emission scenario.

OT and low temperature as temperature that was lower than the OT.

### 3.2. Projected temperature-related YLL

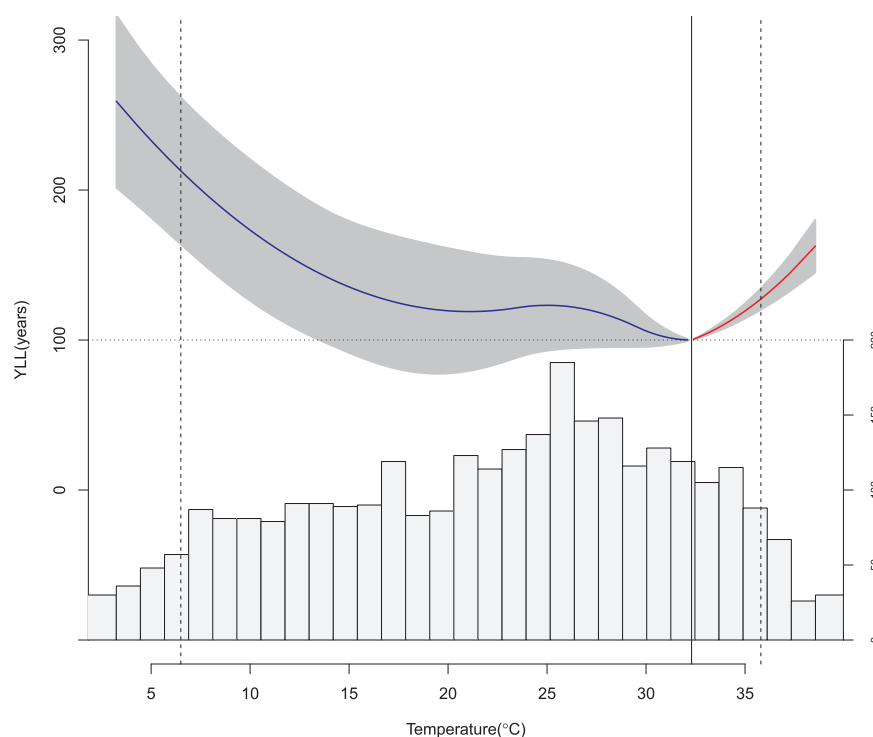
The baseline annual temperature-related YLL for cardiovascular deaths in the elderly was 10,941.4 years, with 615.4 for heat-related YLL and 10,326.0 for cold-related YLL. Table 2 showed the projections and changes in annual temperature-related YLL for cardiovascular diseases in the elderly for the 2050s and 2070s compared with the baseline from 2011. The changes under RCP8.5 scenario in the 2070s are the largest. For instance, heat-related YLL will increase by 200.1% in RCP8.5 in the 2070s, and cold-related YLL will decrease by 30.2% in RCP8.5 in the 2070s. There were increasing heat-related YLL under RCP4.5 and RCP8.5 and decreasing cold-related YLL under all emission scenarios. However, net annual YLL will decrease in future decades compared with the baseline period in Ningbo, China. This indicates the heat-related YLL will be offset by the cold-related YLL in this city with typical subtropical climate in the future. A similar trend was shown for the projections and changes in the annual temperature-related death counts for cardiovascular diseases in the elderly (Supplementary material, Table S3).

Sensitivity analysis shown a same trend when using the Chinese standard life table to calculate YLL, and when estimating YLL from temperature that have significant effects (daily maximum temperature < 12.0 °C and > 32.3 °C) (Supplementary material, Table S4 and Fig. S2).

Monthly analysis showed the monthly temperature-related YLL and death counts both decreased in the cold winter months (December and January), and increased in hot summer months (August) as shown in Table 3. Analysis on the percentage change in monthly temperature-related YLL showed substantial variations across months. Significant percent increases in YLL were found in August, especially in RCP8.5, with incremental increases of 105.0% and 267.6% in the 2050s and 2070s, respectively (Fig. 3).

### 3.3. Projections when considering adaptation and population growth

In this study, we assumed that the population might adapt to heat in the future (Fig. 4). The greater the future adaptation will be, the less influence on YLL related to heat that there will be. The percent adaptation needed to offset the projected heat-related YLL increment related to the temperature increase under 19 GCMs and 3 future climate scenarios are presented in Table 4. No adaptation was required under RCP2.6 for both the 2050s and 2070s. To offset the temperature increase under 19 GCMs and RCP4.5 in 2050s and 2070s, 20.0–39.0% adaptation in population vulnerability to heat would be necessary. The



**Fig. 1.** Overall cumulative exposure-response curves for the effects of daily maximum temperature on years of life lost due to cardiovascular diseases in the elderly in Ningbo, China, 2008–2015. The solid line and the gray areas showed the mean and the 95% confidence intervals, respectively. The dotted lines were the observed temperature. The optimal temperature was 32.2 °C.

increase in heat-related YLL was not be completely offset under 19 GCMs and RCP8.5 for both the 2050s and 2070s, even with an assumed 30% adaptation in our study.

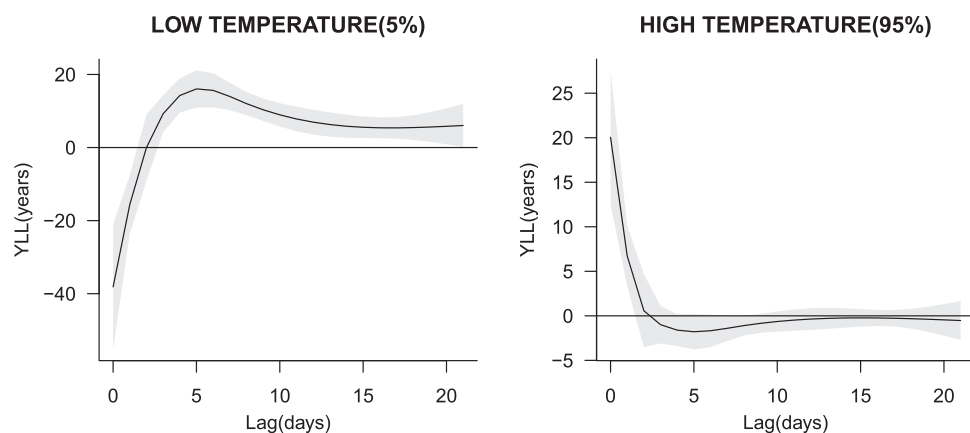
In addition, when taking into consideration population growth of individuals 75 years and older in China provided by the UN, projected heat-related YLL from cardiovascular diseases will be amplified. Fig. 5. demonstrated the projected heat-related YLL from cardiovascular diseases in the elderly when considering both adaptation and population change, along with the results when assuming either no adaptation or no population change. Under the UN population growth scenario, heat-related YLL due to cardiovascular diseases increased rapidly from 2011 to the 2050s and 2070s under 19 GCMs and 3 climate scenarios, with an increase range from 3.1 to 11.5 times compared with the baseline, even with 30% adaptation.

#### 4. Discussion

This is the first study that projected the influence of temperature on cardiovascular diseases in the elderly under different GCMs and future climate change scenarios using the indicator of YLL. Compared with most previous studies that investigated the whole population (Li et al.,

2015, 2018), we focused on the elderly. Although the same trend of increased heat-related cardiovascular deaths was exhibited, a more pronounced effect was observed in the elderly. For instance, the heat-related deaths from cardiovascular diseases are projected to increase by 135% under RCP8.5 in the 2080s compared with the baseline, for the whole population (Li et al., 2015), while our study indicates that heat-related YLL from cardiovascular deaths will increase by more than 200% under RCP8.5 in the 2070s compared with the baseline in the elderly. Aging is considered to increase the risk of temperature-related adverse health effects because of the age-related decline in the body's ability to thermoregulate, as well as social and behavioral factors, such as living alone and taking medications (Bobb et al., 2014). Thus, the elderly population is particularly vulnerable to the health effects of global warming.

Although many scientists considered the future increase in heat-related deaths is unlikely to be offset by the reduction of cold-related deaths (Costello et al., 2009; McMichael et al., 2002), our results suggested that net annual temperature-related deaths may vary at different study locations. And the results were consistent with previous studies conducted in Melbourne, Australia, 11 Canadian cities and 28 major US cities, which also indicated decreased burden of temperature-related



**Fig. 2.** The delayed effects of daily maximum temperature on years of life lost due to cardiovascular diseases in the elderly in Ningbo, China, 2008–2015. The solid line and the gray areas showed the mean and the 95% confidence intervals, respectively. The curves were computed based on temperatures corresponding to the 95th & 5th percentiles and compared with the optimal temperature.

**Table 2**

Projections and changes in annual, heat, and cold temperature-related years of life lost for cardiovascular diseases in the elderly under 19 global-scale climate models and 3 different future climate scenarios in Ningbo, China.

Periods	Scenarios	Projection(years)			Change(years)		
		Heat	Cold	Whole year	Heat	Cold	Whole year
2011	Baseline	615.4	10,326.0	10,941.4	–	–	–
2050s	RCP2.6	592.3	9633.6	10,225.9	– 23.1	– 692.4	– 715.5
	RCP4.5	761.1	9318.8	10,079.9	145.7	– 1007.2	– 861.5
	RCP8.5	964.2	8671.8	9636.0	348.8	– 1654.2	– 1305.4
2070s	RCP2.6	608.4	9603.9	10,212.3	– 7.0	– 7221.0	– 729.1
	RCP4.5	1006.0	8762.2	9768.2	390.6	– 1563.8	– 1173.2
	RCP8.5	1878.8	7489.6	9368.4	1263.4	– 2836.4	– 1573.0

Results were presented as the projection and changes in the 2050s and 2070s versus the baseline. The projections and changes were calculated as the average value under the 19 global-scale climate models. Baseline was analyzed using the data between January 2008 to December 2015 centered on 2011 in Ningbo, China.

mortality (Guo et al., 2016; Davis et al., 2004; Martin et al., 2012). Additionally, consistent with other studies (Zhang et al., 2017; Liu et al., 2015), the heat effect was relatively immediate, and the cold effect was predominant with longer time lags in our study. It may be due to the different mechanisms involved in the body's response to heat and cold (Liu et al., 2015), and the underlying causes are still being explored.

In spite of the net annual temperature-related YLL from cardiovascular diseases decreased, we should not reduce efforts to deal with the temperature-related burden of cardiovascular diseases. Heat-related YLL will increase under the medium and high emission scenarios, and a shifting monthly pattern was revealed, with significantly increased YLL in August. Considering climate change is likely to produce more frequent and more intense heatwaves in the future, this will put extra stress on the elderly during the hot summer months, and more preventive measures and interventions are required.

Adaptation to heat was taken into account because people may adapt to the warming climate through improved building design and city planning, implementing early warning systems, increased use of air conditioning, behavioral changes, and so on (Li et al., 2016; Huang et al., 2012, 2013; Gasparrini et al., 2015a). We found that a future 30% adaptation derived from a previous study did not completely offset the increased heat-related YLL from cardiovascular diseases under RCP4.5 in the 2070s and RCP8.5 in both the 2050s and the 2070s in the elderly (Petkova et al., 2014), and corresponding prevention plans should be developed continuously to minimize the adverse effect of heat.

Furthermore, growth of the elderly population was considered. According to the UN scenario of population growth in China, the population 75 years and older will increase rapidly in the 2050s and

2070s. Thus, if no population growth in the elderly was considered, the health burden related to temperature would be greatly underestimated. When considering both the adaptation and population growth, we found heat-related YLL from cardiovascular diseases was predicted to increase 3.1–11.5 times under 19 GCMs and 3 RCPs in the 2050s and 2070s when compared with the baseline in Ningbo, China. These results will be important for developing public health policies and managing the health risk of cardiovascular diseases related to the dual problems of climate change and an aging population.

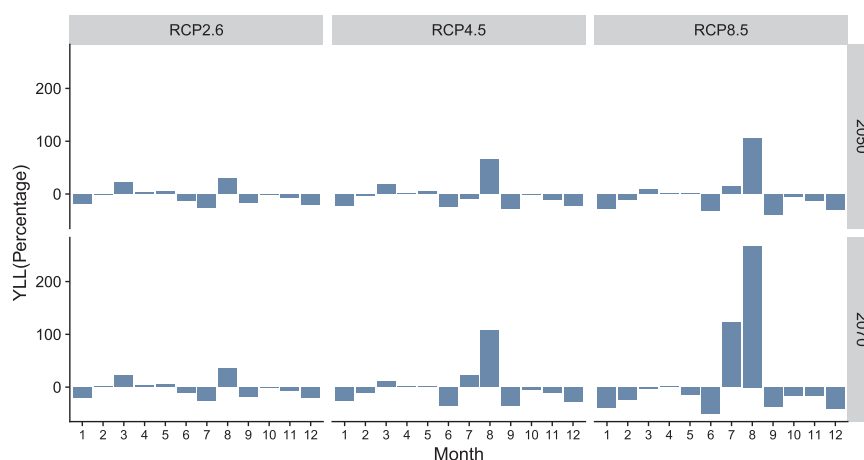
Several advantages of this study deserve mention. First, our study provided the first evidence on future temperature-related burden of cardiovascular disease in the elderly using the indicator of YLL. This indicator considers both the death count and the life expectancy and is a good indicator of disease burden (Guo et al., 2013). However, most studies estimating the health risk from temperature have mainly focused on the influence on morbidity or mortality, and few provided available evidence associated with the temperature-related YLL, especially in the elderly, which is a particularly vulnerable population. Second, future projections were made for an important hybrid problem of climate change and an aging population and provided scientific evidence for guiding policy regarding the problems stemming from the changing demographic and from climate change. Third, monthly analysis was made to explore the variations of temperature-related YLL from cardiovascular diseases, which is important for creating adaptation strategies and allocating resources for cardiovascular diseases, according to the shifting monthly pattern. Furthermore, adaptation of the population to temperature was also considered. The results are important for determining strategies to reduce the temperature-related burden of cardiovascular diseases in the elderly.

**Table 3**

Projections for monthly temperature-related years of life lost and death counts for cardiovascular diseases in the elderly under 19 global-scale climate models and 3 different future climate scenarios in Ningbo, China.

Indicator	Periods	Scenarios	Months												
			January	February	March	April	May	June	July	August	September	October	November	December	
YLL	2011 2050s	baseline	2421.6	1757.2	1021.0	616.9	638.8	373.6	382.6	242.3	336.7	684.8	734.7	1731.0	
		RCP2.6	1977.3	1751.9	1235.7	632.5	669.5	326.9	284.2	312.8	279.6	674.5	683.7	1397.3	
		RCP4.5	1897.9	1710.5	1211.2	627.1	667.7	286.3	352.0	401.8	244.1	672.6	664.5	1344.3	
	2070s	RCP8.5	1763.0	1575.1	1116.3	623.1	647.9	253.6	439.3	496.8	208.7	653.4	645.9	1212.9	
		RCP2.6	1938.8	1769.8	1245.7	631.6	672.2	332.8	287.6	326.7	277.9	672.0	679.6	1377.6	
		RCP4.5	1789.4	1579.1	1130.7	622.8	645.8	245.9	468.6	503.8	216.7	658.4	652.4	1254.5	
	Death counts	RCP8.5	1481.3	1343.8	987.6	620.9	548.3	188.8	853.7	890.7	213.0	578.0	620.5	1041.8	
		2011 2050s	Baseline	204	148	85	42	28	14	38	26	14	38	63	155
			RCP2.6	177	148	98	45	31	13	27	31	12	37	58	132
2070s	RCP4.5		172	145	97	44	31	11	35	38	11	34	56	128	
	RCP8.5	163	137	91	43	29	10	42	46	11	34	53	119		
	RCP2.6	174	149	99	45	31	13	30	32	12	37	57	131		
		RCP4.5	165	137	92	42	29	10	44	46	11	35	54	122	
		RCP8.5	144	123	82	40	24	12	69	71	17	29	49	106	

The projections were calculated as the average value under the 19 global-scale climate models.



**Fig. 3.** Projections of percentage changes in monthly temperature-related years of life lost of cardiovascular diseases in the elderly in the 2050s and 2070s versus baseline (year 2011) under 19 global-scale climate models and 3 Representative Concentration Pathways scenarios in Ningbo, China.

Although we incorporated a range of uncertainties related to future projections, including 19 GCMs and 3 RCPs, population growth and adaptation, our study still has some limitations. First, we used temperature data from fixed sites rather than individual data, which might lead to measurement errors, and the errors may bias the results toward the null hypothesis. Second, adaptation to cold was not considered, because compared with the consistent results of population adaptation to heat, the results of adaptation to cold remain mixed (Åström et al., 2013; Chung et al., 2017; Lee et al., 2018; Vicedo-Cabrera et al., 2018). Just as one comment point out that “Climate change adaptation: no one size fits all” (Hansen and Bi, 2017), this topic should be addressed more comprehensively in further studies. Third, the data in the study were limited to one city in a subtropical region, so generalizing the results to other geographic areas should be done with caution. Further improvements are required for future studies.

## 5. Conclusions

This study presented future projections for the temperature-related burden of cardiovascular diseases using the indicator of YLL in the elderly, which is a particularly vulnerable population. Although the net annual temperature-related YLL due to cardiovascular diseases displayed a decreasing trend, shifting monthly patterns were revealed in this southern China city with typical subtropical climate. The heat-related YLL from cardiovascular diseases is projected to increase 3.1–11.5 times under 19 GCMs and 3 RCPs in the 2050s and 2070s compared with the baseline in 2008–2015, even when taking 30% adaptation into consideration. The results provided evidence for policy making and resource allocation to face the dual problem of climate

**Table 4**

The percent adaptation needed to offset the projected heat-related YLL increase under 19 global-scale climate models and 3 different future climate scenarios in Ningbo, China.

Periods	Scenarios	Adaptation (%)
2050s	RCP2.6	–
	RCP4.5	20.0
	RCP8.5	35.0
2070s	RCP2.6	–
	RCP4.5	39.0
	RCP8.5	> 50.0%

The projections were calculated as the average value under the 19 global-scale climate models. No adaptation is required under RCP2.6.

change and an aging population.

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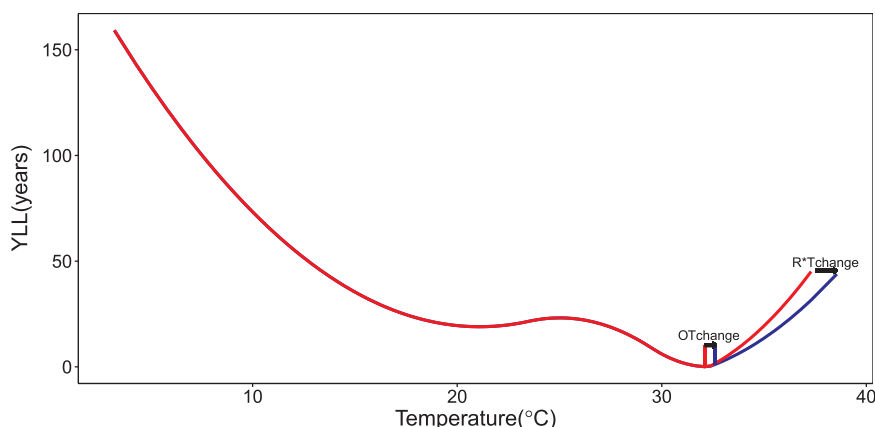
We thank the Ningbo Municipal Center for Disease Control and Prevention and the Ningbo Meteorological Bureau for providing the health data and the meteorological data, respectively.

## Conflict of interests

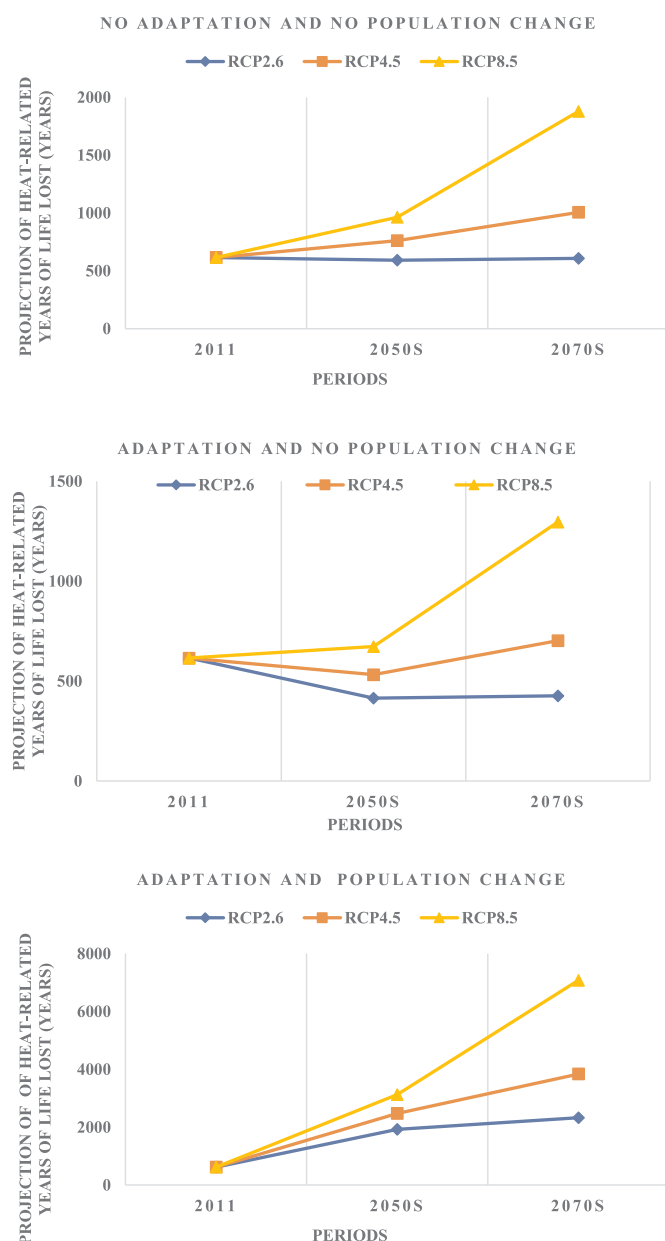
The authors declare that they have no competing interests.

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**Fig. 4.** Projections of years of life lost according to scenarios of adaptation to heat in Ningbo, China. The blue curve indicated percent reductions in the effects of heat due to future adaptation by  $R \cdot T$  in the temperature space ( $0 < R \leq 1$ ), where  $T$  was effects of heat. OT change represents OT increase, which equals  $OT + R \cdot T \text{change}$ , where  $T \text{change}$  is the time-varying increase in annual mean daily maximum temperatures relative to the baseline (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.).



**Fig. 5.** Projection of heat-related years of life lost from cardiovascular diseases in the elderly in 2050s and 2070s versus baseline in Ningbo, China. From the bottom to down, there are three scenarios: (a) no adaptation and no population change, (b) adaptation and no population change, and (c) both adaptation and population change.

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#### Committee for human subjects research

The work was approved by the Institutional Review Board of Ningbo Municipal Center for Disease Control and Prevention [No. IRB 201603].

#### Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.envres.2018.08.024.

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